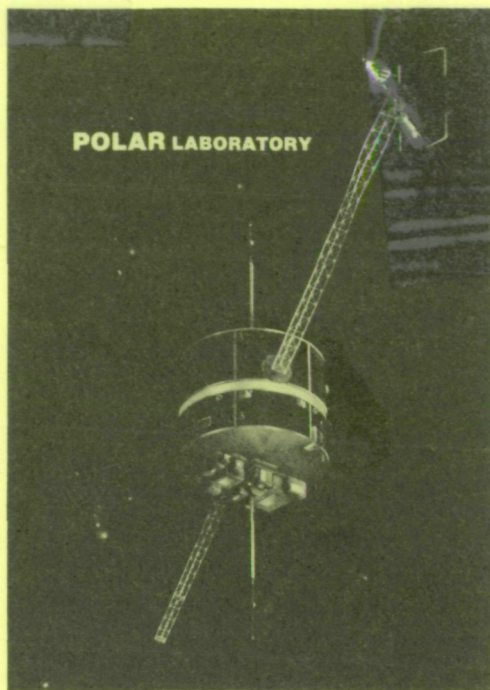


NASA-TM-111360

# Global Geospace Science



## POLAR PLASMA LABORATORY **POLAR**

(NASA-TM-111360) GLOBAL GEOSPACE  
SCIENCE/POLAR PLASMA LABORATORY:  
POLAR (NASA. Goddard Space Flight  
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National Aeronautics and Space Administration  
Goddard Space Flight Center  
GGS Project Office  
Greenbelt, Maryland

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## GGG PROGRAM

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During the past several years, exploration of space has revealed a dynamic and complex system of interacting plasmas, magnetic fields, and electrical currents surrounding the Earth. This region, comprising the solar wind plasma plus the perturbation in the heliosphere caused by the presence of the magnetic Earth, is called *geospace*. The study of the processes taking place in the solar wind, starting at the Sun and continuing through geospace, is the central concern of solar-terrestrial physics. Information concerning geospace has been gathered by past National Aeronautics and Space Administration (NASA) missions. Although successful, these missions have been limited to measuring only what was happening in one region at one time.

Since the 1980s, the collaborative efforts by NASA, the European Space Agency (ESA), and the Institute of Space and Astronautical Science (ISAS) of Japan have led to the conception of the International Solar-Terrestrial Physics (ISTP) Science Initiative consisting of a set of solar-terrestrial missions to be carried out during the 1990s.

This program will combine resources and scientific communities on an international scale using a complement of several missions, along with complementary ground facilities and theoretical efforts, to obtain coordinated, simultaneous investigations of the Sun-Earth space environment over an extended period of time.

The Global Geospace Science (GGG) Project, as a major component of the ISTP Science Initiative, will help fill critical gaps in the scientific understanding of solar and plasma physics by using two spacecraft: the Interplanetary Physics Laboratory (WIND) and Polar Plasma Laboratory (POLAR) strategically located in different orbits to carry comprehensive sets of scientific instruments, which will perform high-resolution measurements.

The ISTP Science Initiative will use simultaneous and closely coordinated measurements from WIND, POLAR, and the Collaborative Solar-Terrestrial Research (COSTR) satellites [(i.e., Geotail, Solar and Heliospheric Observatory (SOHO), and Plasma Turbulence Laboratory (CLUSTER)], which will be launched in the 1990s so an overlap in coverage will be achieved. These measurements of the key regions of geospace will be supplemented by data from Equatorial missions. The Equatorial missions include two series of spacecraft: the Geosynchronous Operational Environmental Spacecraft (GOES) Program of the National Oceanic and Atmospheric Administration (NOAA) and the Los Alamos National Laboratory (LANL) spacecraft from the Department of Energy (DOE). Additional data from other satellites such as NASA's International Magnetosphere Physics (IMP-8) satellite will be used to supplement the data from these missions.

WIND, the first laboratory in the GGG Project, was successfully launched on November 1, 1994; the second laboratory, POLAR, will be launched in December 1995. They will focus on the global flow of energy from the solar wind through the magnetosphere to the ionosphere, and the upper atmosphere.



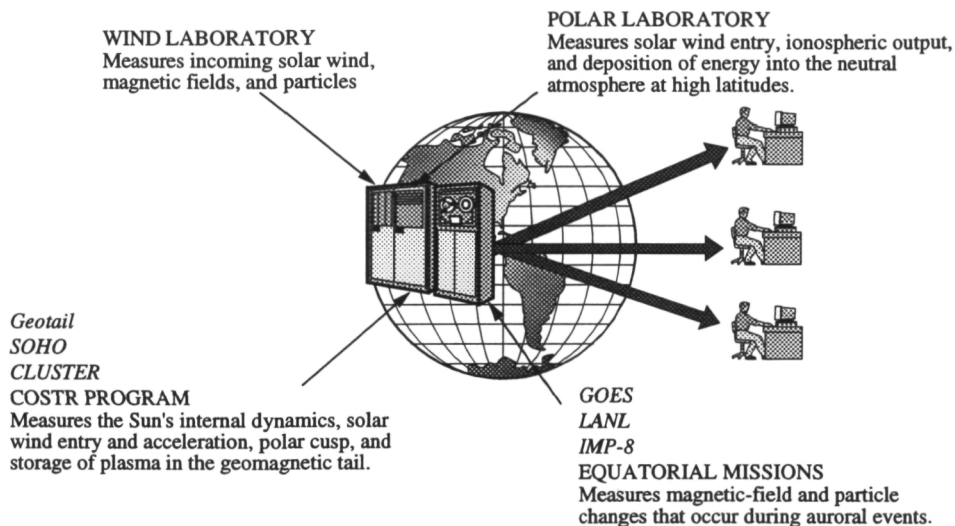
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# GGG MISSION OBJECTIVES

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The key objectives of the GGS Program are as follows:

- Acquisition and analysis of coordinated particle, field, and imaging data from satellites located in four critical regions of geospace: solar wind, geotail, polar magnetosphere, and Equatorial region
- Acquisition and analysis of coordinated geophysical data from ground-based facilities to complement the satellite measurements
- Development of global theoretical and empirical models to assist in the interpretation of measurements



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# THE GLOBAL ENERGY FLOW

## A CRUCIAL FRONTIER FOR SPACE RESEARCH

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The past 20 years of space exploration has led to a revolution in the concept of the Sun-Earth environment, or the solar-terrestrial system. Before the 1950s, Earth was visualized as simply a body traveling in a vacuum around the Sun and being warmed and illuminated by the Sun's emissions.

Information gathered by satellite missions carried out by NASA's Goddard Space Flight Center (GSFC), however, revealed that the Sun and the Earth are actually linked by electromagnetic forces resulting in an interplay that generates and characterizes the protective near-Earth environment and becomes visible as auroral displays in both the Northern and Southern hemispheres.

The regions of space defined by this electromagnetic link include the Sun and its sphere of influence – the heliosphere – and the Earth and its much smaller sphere of influence – geospace. Geospace includes the near-Earth space and reaches toward the Sun, where the Sun's heliosphere is disturbed by Earth's magnetic field.

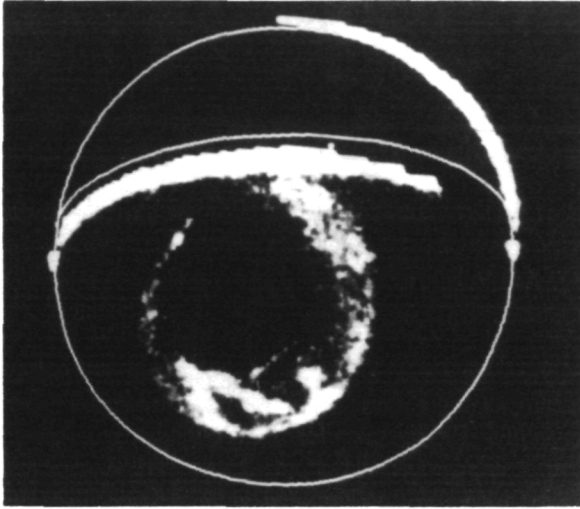
The Sun is an active variable Star with oscillations occurring at its surface and deep in its burning nucleus core in thousands of modes having periods from minutes to days and even centuries. The combination of the Sun's rotation and convection produces a dynamic effect. The solar dynamo generates solar power for magnetic fields, which erupt through the Sun's surface as Sun spots and other so-called coronal transients (e.g., solar X-ray bursts).

The best known terrestrial effects of solar activity are the geomagnetic storms and auroras that occur within a few days following major solar flares. In turn, the auroras contribute to the heating and ionizing of the upper atmosphere that generate the ionosphere, located 100 miles above the Earth, where the neutral atmosphere gives way to ionized plasma.

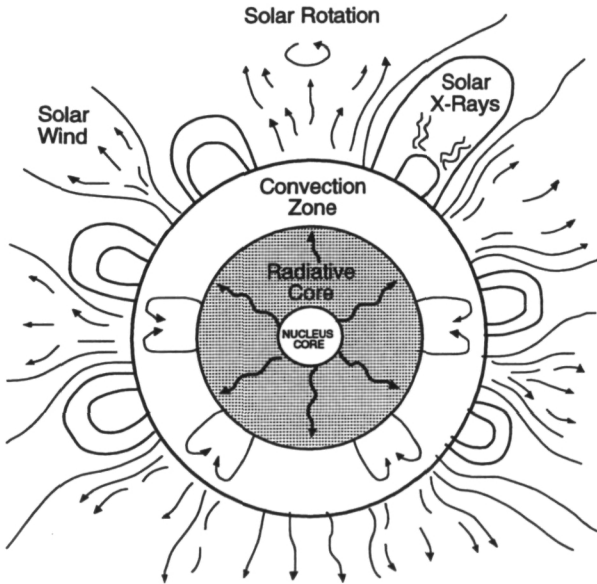
Above the atmosphere, ions and charged particles bounce along and spiral around magnetic field lines, deflected from direct impact on the atmosphere and the people below. Thus, the geomagnetic field forms a mantle protecting people from harmful cosmic radiation.

Disturbances in the space environment in the Earth's neighborhood are consequences of the reactions directly related to the behavior of the Sun. These forces resulting from the violent behavior of the Sun sweep by the Earth causing operational difficulties for radio broadcasters, civilian and military electronics, power distribution, and satellite systems.





Auroral oval surrounding North Pole, imaged in ultraviolet light by NASA's Dynamics Explorer-1 satellite, traces energy deposited into the upper atmosphere by solar wind particles.



The Sun's interior showing the core where the nucleus burning occurs and the convection zone.

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# STRUCTURE OF THE GEOSPACE SYSTEM

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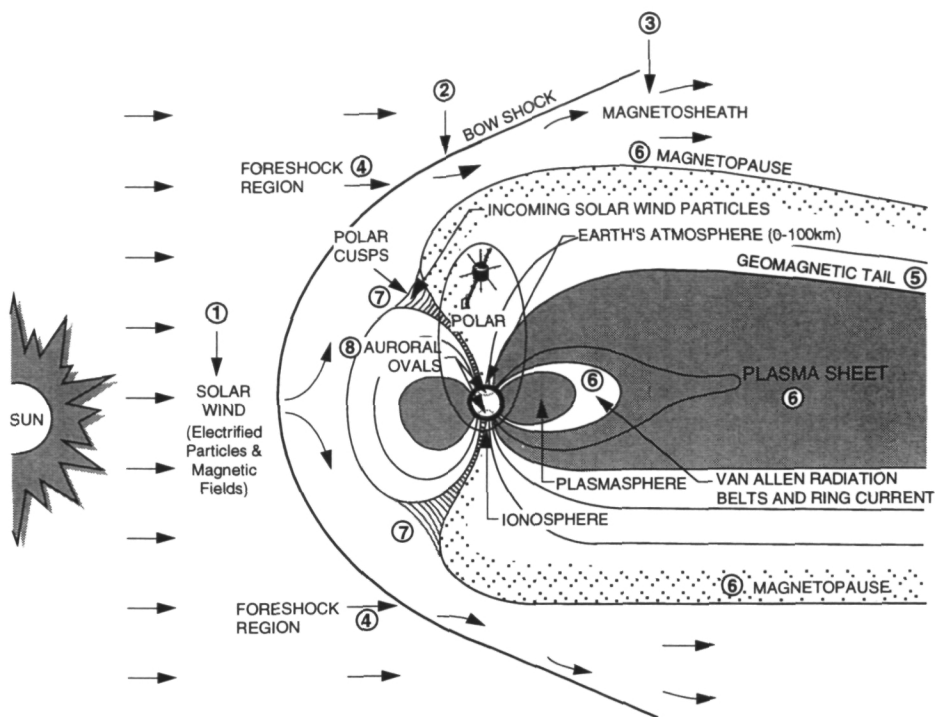
Geospace provides a unique and readily accessible laboratory for *in-situ* investigation of plasma processes that command the attention of both the astrophysicist and the laboratory plasma physicist. Through these plasma processes, energy from matter expelled by the Sun is fed into the Earth's environment, constituting a small but highly significant part of the Earth's total energy budget. Thus, the study of these processes, ranging from the Sun to the Earth is the concern of solar-terrestrial physicists.

The Sun and the heliosphere harbor a large number of fundamental questions that are of consequence not only for the solar system, but also for astrophysics as a whole. To advance knowledge of the Sun, geospace, and Sun-Earth interactions requires that the cause-and-effect relationship be measured between the solar-surface features, and the characteristics of the solar wind (magnetic fields and particles) as it envelops the Earth to create geospace.

The near-Earth space environment, including the upper atmosphere, ionosphere, and the magnetosphere are known as the key regions of geospace. Together with the solar wind and the Sun, the entire system is known as the solar-terrestrial environment.

1. Energy streams out from the Sun toward the Earth in the form of a solar wind of electrified particles. This hot, ionized gas, called a plasma, streams toward Earth at a million miles per hour, carrying electrified particles and magnetic fields from the Sun outward past the planets. Earth is shielded from the full blast of these particles by its magnetosphere, the region around the Earth dominated by the Earth's magnetic field.
2. As the solar wind approaches the Earth's magnetic field, a highly supersonic shock wave is created sunward of the Earth, similar to the shock wave created when a jet plane breaks the sound barrier, but much stronger. This shock wave is called the bow shock.
3. Most of the solar wind particles are heated and slowed down at the bow shock and detour around the Earth through a volume of space called the magnetosheath.
4. Some particles are actually reflected back from the bow shock into the solar wind stream in a region of turbulence called the foreshock.
5. As the solar wind flows around the Earth, it stretches the Earth's magnetosphere out into a long tail, the geomagnetic tail.





6. Some of the particles being carried past the Earth leak through the barrier at the boundary of the Earth's magnetic field, called the magnetopause, and are trapped inside the magnetosphere and stored in the plasma sheet and Van Allen radiation belts.
7. Some particles rush through funnel-like openings at the poles, called the polar cusps.
8. Some energetic particles come down magnetic field lines and enter into the Earth's upper atmosphere. Particles accelerated in the geomagnetic tail excite atoms and molecules in the Earth's atmosphere. These atoms and molecules then emit light known as the Northern and Southern Lights (or auroras) in the auroral ovals, giving a visible signature of this energy transfer from the Sun to the Earth.

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## GGG SCIENCE OBJECTIVES

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The science objectives of the GGS Project include the following:

- Measure the mass, momentum, and energy flows through geospace and understand their time variability
- Obtain detailed knowledge of plasma physical processes important in controlling the behavior of the major components of the geospace system
- Determine the importance of changes in energy input to the Earth's atmosphere caused by geospace processes

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## POLAR-SPECIFIC OBJECTIVES

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- Determine the role of the ionosphere in the substorm phenomena and in the overall magnetospheric energy balance
- Measure plasma energy input through the dayside cusp
- Determine the characteristics of ionospheric plasma outflow and energized plasma inflow to the atmosphere
- Study characteristics of the auroral plasma acceleration regions
- Provide multispectral auroral images of the footprint of the magnetospheric energy deposition into the ionosphere and upper atmosphere



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## GGG SCIENCE

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Solar-terrestrial physics concerns the study of the generation, flow, dissipation of mass, momentum, and energy between the Sun and Earth. When the solar wind reaches the Earth, some solar-wind particles enter the magnetosphere – this coupling between solar wind and Earth indicates that the solar wind can influence the Earth's upper atmosphere.

As the first step to understanding the physical mechanisms and various regions controlling the transport of mass, momentum, and energy in geospace, the GGS Program will use the WIND and POLAR laboratories to perform simultaneous observations of these regions.

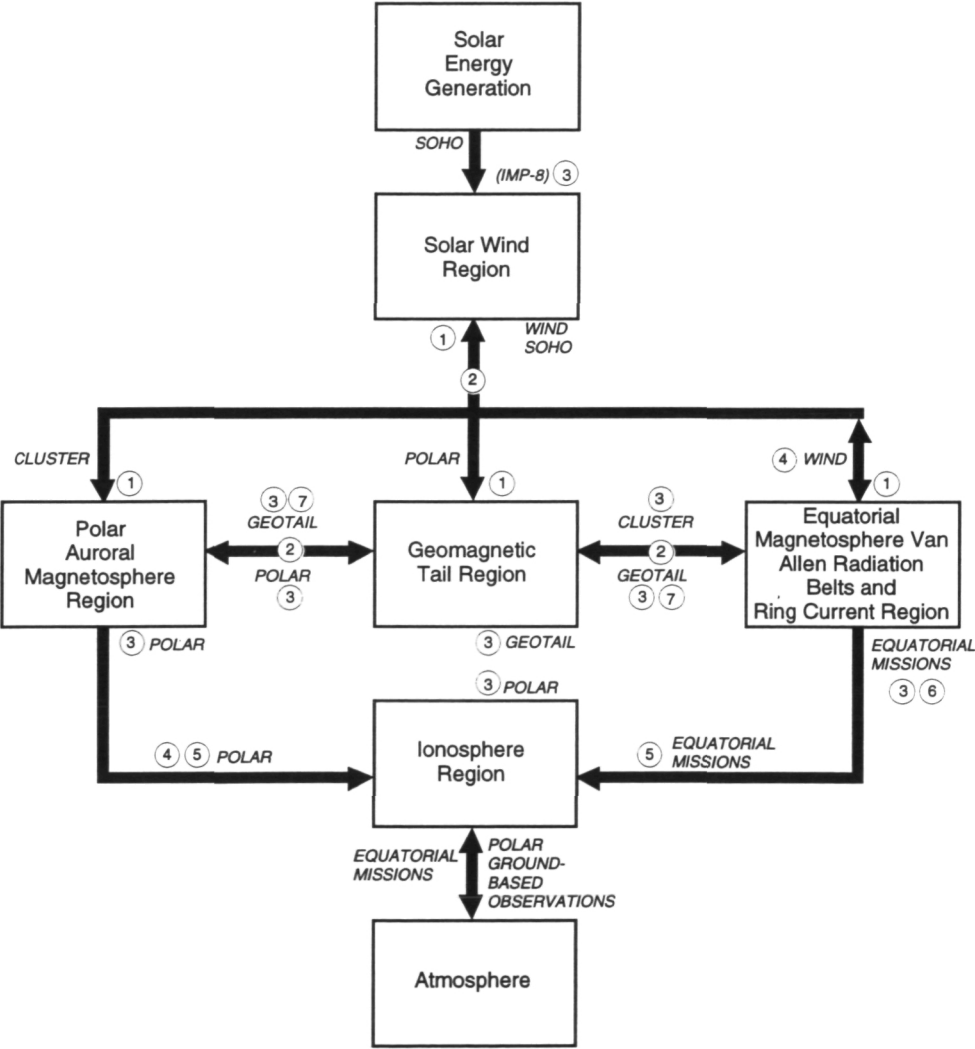
Together with the observations revealed by COSTR and other ISTP Science Initiative-related missions, it will be possible for the first time to look at the complete solar-terrestrial energy chain.

WIND and POLAR along with the other satellites will be located in different orbits to watch the cause and effect of events at the Sun that trickle down, ultimately, into the Earth's atmosphere.

1. Solar wind transfers mass, momentum, and energy into the overall system through polar auroral, geomagnetic tail, and ring current regions.
2. Energy is coupled back and forth between these regions and the solar wind region and between these regions and the ionosphere region. Ultimately, a portion of the mass and energy from the Sun is transferred into the atmosphere, heating and energizing it.
3. The satellites either measure mass and energy within the regions themselves or observe transfer processes across boundaries.
4. The WIND laboratory stationed in the solar wind upstream from the Earth to observe the input of energetic magnetospheric particles and their escape back into the solar wind region.
5. The POLAR laboratory will measure flow of plasma to and from the ionosphere region on auroral magnetic field lines and will observe the deposition of particle energy into the ionosphere region and upper atmosphere.
6. The Equatorial missions will observe and sample the buildup of particles in the Van Allen radiation belts.

7. Geotail will provide extensive simultaneous measurements of entry, storage, acceleration, and transport in the geomagnetic tail region. It will sample the inflation and collapse of the geomagnetotail: what controls it and how coupling occurs between the solar wind input and the Earth's fields.

The combined data set from the satellites and from complementary ground-based observations will be used to construct quantitative models to describe how mass, momentum, and energy from the solar wind are transported across boundaries, stored and energized in the magnetosphere, and subsequently dissipated into the Earth's atmosphere.





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## GROUND-BASED OBSERVATIONS

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Ground-based observations will complement the GGS Program space observations by remote sensing of the magnetosphere to provide coverage of regions between the WIND and POLAR laboratories, COSTR, and other missions. While these satellites are taking measurements in space, ground-based instruments will be studying phenomena near the Earth in the high-latitude ionosphere. This region is the last link in the chain of interactions through which mass, momentum, and energy are transferred from the Sun to the Earth's atmosphere.

Measurements taken by ground-based instruments will indicate the effects of the processes occurring in the magnetosphere (as observed by the satellites) on the Earth's atmosphere. Unlike satellites, ground-based instrumentation can also be used to study phenomena in a particular spatial region over an extended period of time so that changes that occur over long time spans can be observed.

The high-latitude ionosphere acts as a boundary to the processes occurring in the inner and outer magnetosphere, the magnetosheath, and even certain regions of interplanetary space. At boundaries between regions, interactive coupling takes place to allow the transfer of mass, momentum, and energy from one region to another. Measurements taken in the high-latitude ionosphere will contribute to the understanding of the role that boundaries and boundary conditions play in determining behavior of the solar-terrestrial system.

There are four ground-based experiments that support the GGS Mission.

### **CANADIAN AURORAL NETWORK FOR THE ORIGIN OF PLASMAS IN THE EARTH'S NEIGHBORHOOD PROGRAM UNIFIED STUDY (CANOPUS)**

CANOPUS, located in central Canada, provides continuous near real-time measurements of the ionosphere currents, electric fields, and particle precipitation in the Canadian sector of the auroral zone using a cluster of ground-based instruments that provide one and two-dimensional representations of ionospheric current patterns. This data will provide instantaneous information on the structure and dynamics of the global convection pattern, structure of resonant hydromagnetic waves, and global distribution of ionospheric Joule heating.

## **SATELLITE EXPERIMENTS SIMULTANEOUS WITH ANTARCTIC MEASUREMENTS (SESAME)**

SESAME, located at Halley Station, Antarctica, and operated by the British Antarctic Survey uses a cluster of ground-based instruments that measure the components of the solar-terrestrial system from a single site. These measurements will be used to reveal the contrasts in the behavior of the ionosphere – magnetosphere system in the Northern and Southern Hemispheres, providing important insights into the mechanisms involved.

## **SONDRESTROM RADAR**

Like the Halley Station, the Sondrestrom Radar facility, located at Sondre Stromfjord, Greenland, uses a close clustering of various remote-sensing instruments that study the thermosphere, ionosphere, and magnetosphere. The facility's location beneath the dayside auroral oval makes it an ideal site for providing measurements of ionospheric conditions near the polar cusp, the polar cap, and the poleward part of the auroral oval. These regions are associated with the magnetospheric and ionospheric boundaries that are of primary interest to the GGS Mission. The Sondrestrom Radar measures several parameters simultaneously over a broad altitude and, because it is steerable, as a function of latitude and longitude. This data will be used to derive important ionospheric physical characteristics.

## **DUAL AURORAL RADAR NETWORK (DARN)**

DARN is an international network of radar sites located in high latitudes and operated by investigators from the United States, Great Britain, Canada, France, Germany, and Finland. These radars operate by sending a signal in the wavelength of the object to be measured and measuring the signal as it is returned or scattered back. DARN radars use backscatter from ionospheric irregularities to study plasma convection and electric fields in the high-latitude ionosphere. This data will be used for a wide range of global studies.

### **Ground-Based Observations/Investigators**

<b>Investigation</b>	<b>Principal Investigator</b>	<b>Institution</b>
Canadian Auroral Network for the Origin of Plasmas in Earth's Neighborhood Program Unified Study (CANOPUS)	Dr. G. Rostoker	University of Alberta
Satellite Experiments Simultaneous with Antarctic Measurements (SESAME)	Dr. J. Dudeney	British Antarctic Survey
Sondrestrom Radar	Dr. J. Kelly	Stanford Research Institute
Dual Auroral Radar Network (DARN)	Dr. R. Greenwald	The Johns Hopkins University Applied Physics Laboratory

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## THEORY AND MODELING

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The intention behind the GGS Mission is to understand the physical mechanisms and various regions controlling the flow of mass, momentum, and energy throughout the solar wind-magnetospheric systems. Complex physical processes, and their mutual interactions, govern the behavior of plasmas in this system.

The GGS laboratories will provide a measurement network to determine the local state of several key magnetospheric regions. However, because the magnetosphere is a vast interactive system, a comprehensive understanding can be achieved only if local measurements can be related to the large-scale structure and dynamics.

An essential ingredient in the achievement of this understanding is the extensive use of theory and models that link the locally-observed plasma phenomena to the global magnetospheric structure combined with ground-based observations.

The integration of theory and modeling with satellite and ground-based observations represents a new approach to space physics missions that reflects progress in understanding the physical processes that govern the solar-terrestrial physics.

Theoretical tools can model the processes of the magnetosphere within certain scales and specified conditions. These tools provide the investigators with a framework for resolving the expected theoretical results of investigations with actual observations made simultaneously by satellites located in different regions of the magnetosphere. The models are derived from two approaches that describe the plasma dynamics of the magnetosphere:

- Continuum magnetohydrodynamics (MHD) theory describing larger-scale fluid dynamics
- Collisionless Vlasov kinetic theory describing microscale particle physics

Three types of models are being used by investigators to help construct a global picture of the magnetosphere:

# GLOBAL SCALE

On this scale, the largest, MHD models display the flow of mass, momentum, and energy as if the plasmas were a fluid. The theory describes coupling between large regions and the cross-field currents that connect them.

# MICROSCALE

On this scale, the smallest, kinetic models characterize the motions of individual particles according to their physical properties.

# MESOSCALE

On this scale, hybrid models combine fluid elements of large-scale structures, such as the solar-wind geomagnetic tail plasma — with kinetic particle effects.

The four principal investigator theory teams that support the GGS Program component of the ISTP Science Initiative are shown below.

**Theory and Modeling Investigators**

Theory and Modeling	Principal Investigator	Institution	Type of Model
Mission-Oriented Theory	Dr. M. Ashour-Abdalla	University of California at Los Angeles	Global, Microscale, and Mesoscale processes
Theory, Modeling, and Simulation Support	Dr. D. Papadopoulos	University of Maryland	Global, Microscale, and Mesoscale processes
Theory, Simulation, and Modeling	Dr. M. Hudson	Dartmouth College	Microscale and Mesoscale processes
Modeling of the Atmosphere-Magnetosphere-Ionosphere System	Dr. M. Rees	University of Alaska	Modeling of the Atmosphere-Magnetosphere-Ionosphere (MAMI) system focusing on response of the ionosphere and upper atmosphere-to-magnetospheric input of energy and momentum carried by particles and fields

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# POLAR LABORATORY

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The POLAR laboratory was designed and built by Lockheed Martin Corporation, Astro-Space Division, East Windsor, New Jersey, under the technical direction of GSFC. The laboratory is spin-stabilized and is cylindrically shaped, consisting of a reinforced structure for carrying scientific instruments, support subsystems, and body-mounted solar array panels. The laboratory support subsystems are located on decks within the laboratory structure. Openings in the solar array provide viewing ports required for radial viewing instruments.

The POLAR laboratory has a complement of eleven instruments, each of which has several components and some of which have more than one sensor. The POLAR instruments are:

- Magnetic Fields Experiment (MFE)
- Electric Fields Instrument (EFI)
- Plasma Waves Investigation (PWI)
- Fast Plasma Analyzer (Hydra)
- Thermal Ion Dynamics Experiment (TIDE)
  - TIDE/Plasma Source Instrument (PSI)
- Toroidal Imaging Mass Angle Spectrograph (TIMAS)
- Charge and Mass Magnetospheric Ion Composition Experiment (Cammice)
- Comprehensive Energetic-Particle Pitch-Angle Distribution (CEPPAD)
  - CEPPAD/Source-Loss Core Energetic Particle Spectrometer (SEPS)
- Ultraviolet Imager (UVI)
- Visible Imaging System (VIS)
- Polar Ionospheric X-Ray Imaging Experiment (PIXIE)

The physical characteristics for POLAR are as follows:

- MAIN BODY stowed for launch: 8.2 ft (2.5m) tall; 7.87 ft (2.4m) in diameter
- WEIGHT:
  - POLAR laboratory total weight: 2860 lbs (1300 kg)
  - POLAR laboratory fuel weight: 662 lbs (301 kg)
  - POLAR laboratory dry weight: 2198 lbs (999 kg)



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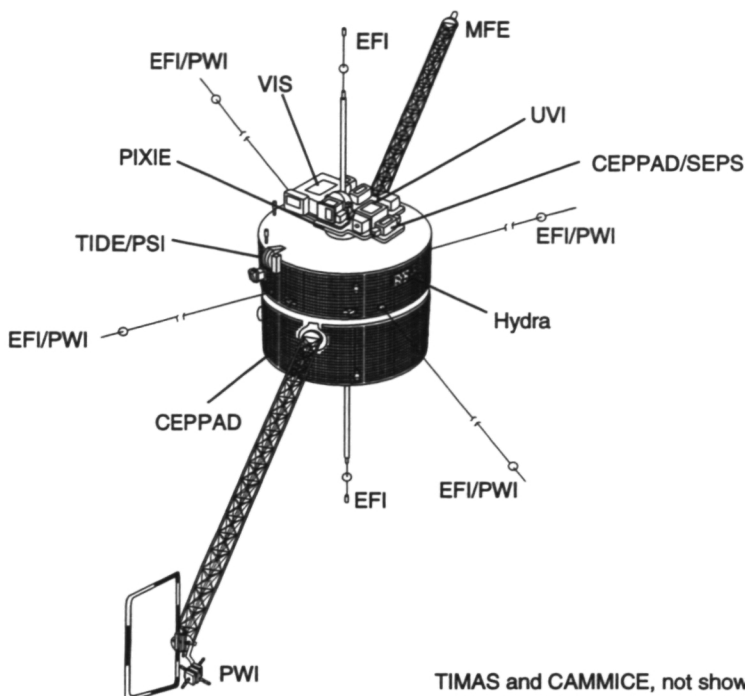
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## INSTRUMENT LOCATIONS

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The POLAR laboratory carries eleven high-resolution instruments.



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## SUPPORT SUBSYSTEMS

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The following subsystems support operation of the POLAR laboratory:

- Despun Platform
- Structural and Mechanical
- Power
- Thermal Control
- Reaction Control
- Attitude Control and Determination
- Communications
- Command and Data Handling

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## DESPUN PLATFORM SYSTEM

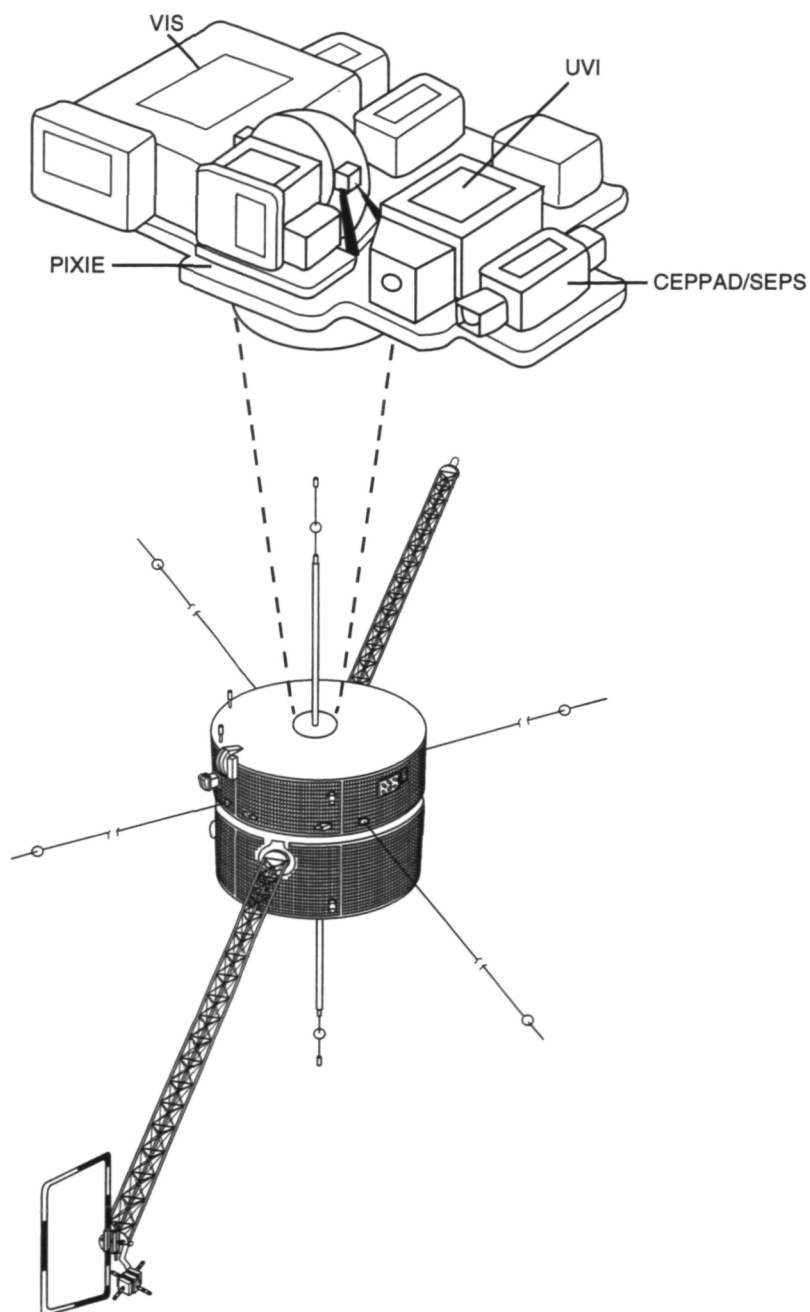
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The POLAR laboratory explores the interactions in the terrestrial portion of the Sun-Earth system. The spacecraft is spin stabilized in a highly-eccentric polar orbit to survey the ionosphere and upper atmosphere. A despun platform provides an inertially-stable mounting surface for four instruments: The VIS, UVI, PIXIE, and CEPPAD/SEPS. These instruments will provide multi-spectral images of the aurora and measurements of high-energy ion composition.

The orientation and control of the despun platform is performed by the Despun Platform Mechanism (DPM), a high-precision electromechanical device that will maintain continuous near-inertial orientation of the platform while the main body of the spacecraft rotates at 10 rpm.

The principal components of the DPM are motors, bearings, control electronics, a retention/release mechanism with diaphragms, and a slip-ring assembly with 69 rings that provides uninterrupted electrical contact between the platform instruments and the main body of the spacecraft. Control is maintained by dedicated software resident in the spacecraft's command and attitude processor.

The mechanism was designed and built by Honeywell Satellite Systems Operations in Glendale, Arizona. The development effort is complemented by a rigorous test program, including a slip-ring life test and an engineering model closed-loop test.



**POLAR Despun Platform Instrument Configuration**

# POLAR INSTRUMENTATION

The following tables describe the functions of the scientific instruments carried on POLAR, the physical parameters to be measured, and principal investigators. Nearly all particle measuring instruments are capable of imaging the three-dimensional phase space with high-angular and time resolutions.

## The Global Geospace Science Program and its Investigations

Measurement	Typical Spectral Coverage	Spacecraft			
		WIND	POLAR	Equatorial Missions	Geotail
<b>Electromagnetic Fields</b> Vector Magnetic Fields Vector Electric Fields Plasma Waves	<p>1 Hz      1 kHz      1 MHz</p> <p>frequency →</p>	*	*	*	*
<b>Plasma &amp; Energetic Particles</b> 3-D Plasma Electrons & Ions Plasma Ion Composition 3-D Energetic Electrons & Ions Energetic Ion Composition Cosmic Ray Electrons & Ions	<p>1 eV      1 keV      1 MeV</p> <p>Energy, Energy/Chg. or Energy/NUV →</p>	*	*	*	*
<b>Global Auroral Imaging</b> Visible Ultraviolet X-Ray	<p>10<sup>3</sup> nm      10 nm      0.1 nm</p> <p>← Wavelength</p>		*		
<b>Cosmic &amp; Gamma Ray Bursts</b>	<p>10 keV      1 MeV</p> <p>← Energy</p>	*			

The science instrument payloads on POLAR will be unique in the following ways:

- Provide measurements of the full three-dimensional angular distributions and the ion mass identities of plasmas over the full range of energies that are important in the energy and mass budget of the magnetosphere
- Collect the first set of simultaneous measurements of the processes occurring in each of the four key regions of geospace
- Provide the first detailed measurements of plasma flows and particle beams that

occur nearly parallel to the ambient magnetic field during important transport and energization processes

- Obtain the first, essentially continuous, multispectral, global auroral imaging observations of the upper atmosphere-to-magnetospheric energy input at high latitudes

These measurements are achieved in large part by incorporating microprocessor-based data systems that provide not only a significant amount of autonomy to the instruments, but also the ability to reconfigure and optimize the dynamic range, nature, and frequency of the observations based on the data acquired from the POLAR laboratory. To accommodate these capabilities, the POLAR on-board C&DH Subsystem will provide the capability to issue selective real-time or stored, time-tagged commands and loading and updating the instrument memories. The instrument systems provide both direct readout (real-time) and on-board recording (playback) of scientific data during day and night operations.

### **POLAR Principal Investigators**

<b>Investigation</b>	<b>Principal Investigator</b>	<b>Institution</b>
Magnetic Fields Experiment (MFE)	Dr. C. Russell	University of California at Los Angeles
Electric Fields Instrument (EFI)	Dr. F. Mozer	University of California at Berkeley
Plasma Waves Investigation (PWI)	Dr. D. Gurnett	University of Iowa
Fast Plasma Analyzer (Hydra)	Dr. J. Scudder	University of Iowa
Thermal Ion Dynamics Experiment (TIDE)	Dr. T. Moore	Marshall Space Flight Center
TIDE/Plasma Source Instrument (PSI)	with TIDE	Southwest Research Institute
Toroidal Imaging Mass-Angle Spectrograph (TIMAS)	Dr. E. Shelley	Lockheed Martin/Palo Alto Research Laboratory
Charge and Mass Magnetospheric Ion Composition Experiment (Cammice)	Dr. T. Fritz	Boston University
Comprehensive Energetic-Particle Pitch-Angle Distribution (CEPPAD)	Dr. B. Blake	Aerospace Corporation
CEPPAD/Source-Loss Cone Energetic Particle Spectrometer (SEPS)	with CEPPAD	Lockheed Martin/Palo Alto Research Laboratory
Ultraviolet Imager (UVI)	Dr. G. Parks	University of Washington
Visible Imaging System (VIS)	Dr. L. Frank	University of Iowa
Polar Ionospheric X-Ray Imaging Experiment (PIXIE)	Dr. D. Chenette	Lockheed Martin/Palo Alto Research Laboratory



## POLAR Instrument Description

Instrument	Power Consumption (W)	Weight (kg)	Data Rate* (bps)	Science Objectives
MFE	5.1	5.0	830	Magnetic Fields
EFI	9.4	33.2	2500	Electric Fields
PWI	13.8	18.9	4000	Plasma Waves
Hydra	13.7	18.5	4900	Thermal Plasma
TIDE	9.0	16.3	4000	Thermal Ions
TIDE/PSI	13.1	16.5	with TIDE	Plasma Source
TIMAS	10.0	15.8	4110	Ion Mass Analysis
CAMMICE	8.4	12.0	1410	Charged Particles
CEPPAD	8.0	12.4	4580	Charged Particles
CEPPAD/ SEPS	5.2	3.4	with CEPPAD	Charged Particles
UVI	21.7	20.9	12,000	UV Imaging
VIS	30.0	28.5	11,000	Visible Imaging
PIXIE	9.0	24.7	3500	X-Ray Imaging

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## SUPPORT SUBSYSTEMS DESCRIPTION

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The following is a basic description of the subsystems that support operation of the POLAR laboratory during its mission.

### STRUCTURAL AND MECHANICAL

The POLAR laboratory is cylindrically shaped and designed to support the scientific instrument payload and support subsystems required for operation. This includes:

- Primary structure to withstand anticipated ground, launch, and in-orbit environments
- Structural interface to the Delta launch vehicle payload attachment fitting
- Laboratory hardware for routing purge gas to instruments during ground operations
- All mechanisms for deployable elements of POLAR after reaching orbit, such as EFI and PWI masts, wires, and lanyard deployable booms
- The despun platform and despun platform mechanisms to support the imaging instruments

The primary structure for POLAR consists of a center cone, two equipment decks, and a solar array composed of 12 curved solar array panels and two -Z closure panels. Six propellant tanks are mounted symmetrically around the center cone. Secondary structure includes all brackets and supports necessary for mounting instrument and laboratory components. Apertures in the solar array are provided for instruments and attitude sensors that require a radial-look field of view.

## POWER

The Power Subsystem supplies, controls, converts, regulates, and distributes electrical power to the POLAR laboratory subsystems and instruments. It includes a solar array, three 26.5-ampere hour, 16-cell nickel-cadmium storage batteries, a redundant power subsystem electronics (PSE) and battery charge unit, a power junction assembly and protective devices.

The 14 panel (12 curved, 2 flat mounted on -z closure panel) solar array supplies the laboratory subsystems and provides power required for charging the batteries. During the sunlight portion of the orbit the cells convert solar energy to electrical energy for both laboratory operation and battery charging. The storage batteries supply power for eclipse operation. Two batteries are sufficient to support the mission.

The PSE unit distributes power provided by the solar array and batteries to the laboratory loads. The PSE unit controls the regulation of power to 28 volts  $\pm$  2% at all times. The supply delivers a minimum of 417 watts of power at the beginning of life (BOL) at a 90° Sun angle; this will be reduced to 348 watts at end of life (EOL). The average power load at EOL is 343 watts at this same Sun angle.

Parameters	Characteristics
Regulated Output Voltage	28 volts $\pm$ 2%
Solar Array BOL Power	417 watts (90° Sun angle)
Solar Array EOL Power	348 watts
Average Power Load at EOL	343 watts

## THERMAL CONTROL

The POLAR Thermal Control Subsystem (TCS) uses both passive and active methods to keep laboratory and instrument components within acceptable temperature ranges during all phases of the mission. Passive thermal control is provided by thermal paints, coatings, and multilayers of thermal insulation. Active control is provided by electronically-controlled heaters to continuously modulate the temperature of more critical components, such as instruments and propellant tanks. Temperature sensing is provided by various types of thermistors, placed throughout the laboratory in the vicinity of critical components.

## REACTION CONTROL

The Reaction Control Subsystem (RCS) provides propulsive orbit-adjust capability to execute POLAR laboratory Delta-V, spin-rate, and precession control maneuvers throughout all phases of the mission. The RCS is a single-stage hydrazine blowdown propulsion system, which consists of 6 propellant tanks and 12 reaction engine assemblies (4 radial, 4 axial, and 4 spin precession) located externally on the laboratory.

## ATTITUDE CONTROL AND DETERMINATION

The POLAR laboratory is spin stabilized at  $10 \pm 0.1$  revolutions per minutes (rpm) about the axis of its cylindrically-shaped body. As POLAR moves through space, external forces (e.g., Earth's magnetic and electrical fields, aerodynamic drag, and solar radiation) can induce attitude perturbation. The Attitude Control and Determination (ACAD) Subsystem is designed to perform all attitude and orbit corrections required to maintain the laboratory position within specified limits throughout the mission.

The ACAD Subsystem consists of two horizon-sensor assemblies, two Sun-sensor assemblies, and an accelerometer unit. Nutation and spin dampers are used after launch to provide a damping action for reducing unwanted laboratory oscillatory motion.

In addition, the POLAR ACAD Subsystem includes two dynamic balancers to adjust the spacecraft for wobble free fine pointing of the despun platform. Each dynamic balancer consists of a 6 lb motor driven mass on a 40-inch lead screw. As minor unbalances in the spacecraft are detected the dynamic balancer masses can be moved to improve the alignment of spacecraft spin axis with the despun platform rotation axis. The despun platform instrument images will then be analyzed for any remaining "wobble" effects and to assess the need for additional dynamic balancer position changes.

Parameters	Characteristics
Stabilization	Spin Stabilized
Pointing Direction	Orbit Normal $\pm 1^\circ$
Pointing Control, Spin Axis	$\pm 1^\circ$
Attitude Determination	$0.2^\circ/0.09^\circ$ Spin Axis/Phase
Spin-Rate	$10 \pm 0.1$ rpm
Spin-Rate Control	$\pm 0.1\%$
Pointing Control, Despun Platform	$\pm 0.1^\circ$

## COMMUNICATIONS

The Communications Subsystem consists of two redundant transponders, two power amplifiers, two electrical power converters, two receive and two transmit quadrifilar helix-type hemispheric (hemi) antennas, and a prime mission belt antenna to provide command, telemetry, and ranging functions. Transmission of the command, telemetry, and ranging signals will be performed simultaneously.

The Communications Subsystem provides all uplink and downlink communications via S-band between the POLAR laboratory and the Deep Space Network (DSN).

The basic functions of the Communications Subsystem are:

- Receive and demodulate the 16-kHz subcarrier frequency containing the uplink command stream
- Provide baseband non-return-to-zero (NRZ)-L command data to the C&DH Subsystem
- Transmit real-time and playback (recorded) downlink telemetry data streams to the DSN
- Provide turnaround ranging via the DSN square-wave ranging system

Communications characteristics:

- Telemetry rate (real-time): 55.65 kbps
- Playback rate (recorded): 512 or 256 kbps
- PWI wideband real-time data: 256 kbps
- Command rate: 1000 bps

### COMMAND

The DSN, operated by Jet Propulsion Laboratory (JPL), will control the operation of the POLAR laboratory by computer-controlled commands received from the Project Operations Control Center (POCC) and then transmitted to the laboratory via S-band uplink at 2085.688 MHz. The receiver part of the transponders, receives the command signals and sends them to one of the command attitude processors (CAPs). Throughout all phases of the mission, the CAP processes the commands and distributes them to the applicable units within the laboratory via the Command Distribution Unit (CDU).

Command characteristics:

- Two redundant receiver systems
- Two redundant CAPs
- S-band Frequency: 2085.688 MHz
- Polarization (belt): Right-Hand Circular
- Polarization (hemi): Left-Hand Circular
- Carrier Modulation : Phase Shift Keying/Phase Modulation
- Baseband Rate: 1000 bps
- Command Frame Length: 64 bits

### TELEMETRY

Two redundant processors on board the POLAR laboratory process and multiplex data signals from the laboratory subsystems. Two redundant transponders, located in the Communications Subsystem, transmit these signals to the DSN by a 2265.0- MHz radio signal and are forwarded in real time to the POCC. Telemetry signals provide housekeeping, instrument, attitude determination, and command verification data to enable POCC

personnel to evaluate the performance of the laboratory and its subsystems for operational control and maneuvering of the laboratory.

Telemetry characteristics:

- Two redundant transponders
- Carrier Frequency: 2265.0 MHz
- Carrier Modulation: Phase Modulation (PM)
- Premodulation: PM modulation of real-time telemetry on a 1.28-MHz subcarrier
- Recorded Playback Data: Modulated directly on the 2265.0-MHz carrier frequency
- Baseband Data Type: NRZ-L
- Reed-Solomon Encoding: (223 and 255)
- Convolutional Encoding: Rate 1/2 Constraint Length 7

### *RANGING*

Two redundant transponders, located in the Communications Subsystem, will transmit 128-kHz square-wave ranging signals via downlink on command from the DSN. The ranging signals permit tracking of the POLAR laboratory in orbit at all times during early orbit and normal operations. The DSN forwards the ranging signals at scheduled intervals to GSFC for use in orbit determination.

Ranging characteristics:

- Two redundant transponders
- Carrier Frequency: 128-kHz square wave
- Orbit position determination accuracy:  $\pm 10$  km

## **COMMAND AND DATA HANDLING**

The C&DH Subsystem for the POLAR laboratory consists of redundant command and attitude processors, internally redundant command and distribution and telemetry modules, a despun platform remote interface unit, a redundant crystal oscillator, two digital tape recorders, and two pyro relay assemblies.

The C&DH Subsystem collects, formats, and records science and engineering data from the laboratory subsystems for transmission to the DSN. The command equipment will receive, process, and execute real-time commands, as well as execute commands from on-board command storage. The data handling system collects POLAR instrument and subsystem data and routes it to the transponders in the Communications Subsystem for real-time transmission to the DSN. Alternately, the data can be routed to digital tape recorders for storage and dump at a later time.

The C&DH Subsystem provides the following basic functions:

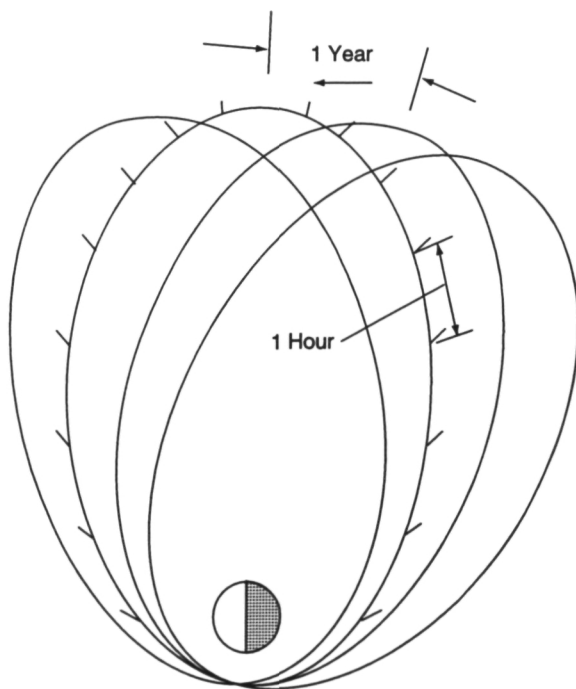
- Receives, decodes, and distributes all commands necessary for POLAR laboratory operation
- Collects, formats, and stores laboratory telemetry (housekeeping and science)
- Convolutional and Reed-Solomon encoding of the real-time and playback data streams; premodulation of real-time data stream, and formulation of real-time/playback downlink data stream
- Generation, distribution, and maintenance of all laboratory timing signals, including the laboratory clock
- Collection, processing, and distribution of laboratory spin-phase information, timecode, and magnetic data as required by the instruments
- Command of laboratory thrusters and electro-explosive devices



# THE POLAR ORBITS

## Polar Orbit/Attitude

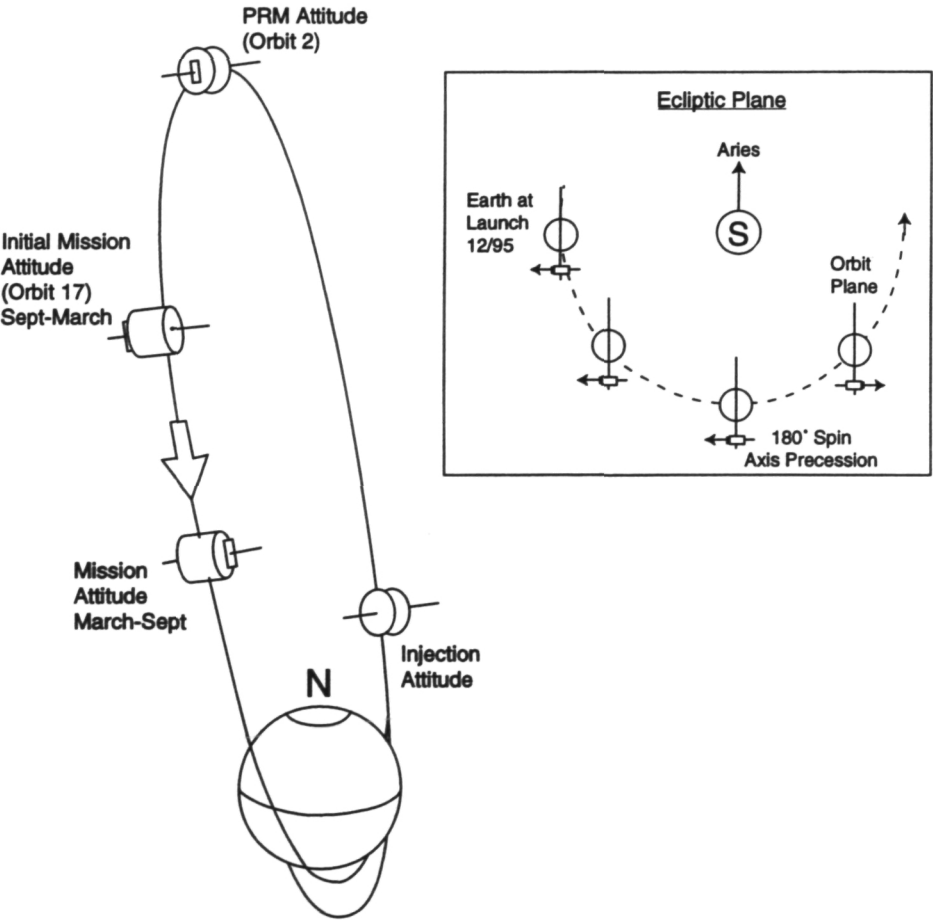
Parameters	Characteristics
Apogee	9.0 Re geocentric
Perigee	1.8 Re geocentric
Inclination	86.0 deg
Rate of change of argument of perigee	15.7 deg/year
Initial ascending node	335.98 deg
Angle between the spacecraft Sun vector and the negative orbit normal (initial)	148.85 deg
Period	17 hrs 38 min
Initial operational spin-axis direction	Negative orbit normal (spacecraft "skids" around orbit)
Spin rate	10 rpm
Apogee precession	From night, over north pole, to day

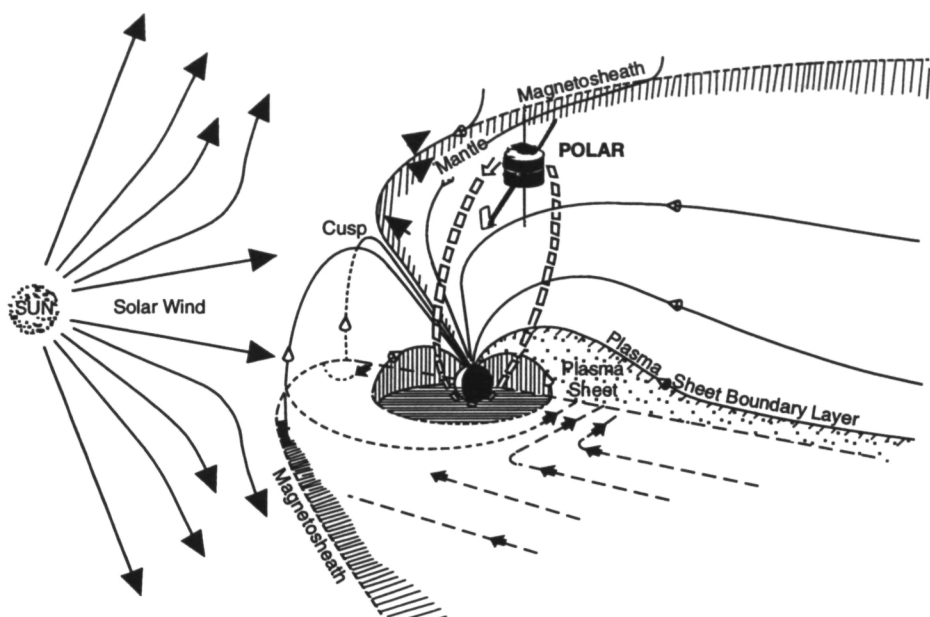


# MISSION PROFILE

## Mission Event Highlights:

- Launch, ascent, separation, initial contact, and spindown (Day 1)
- 180° precess to perigee raise maneuver (PRM) attitude (Day 2)
- Perigee raise (Day 3 -6)
- Pyro firings and deployments (Day 8 - 20)
- Spin-rate changes throughout deployments
- Instrument activation and checkout (Day 3 - 26)
- Platform despin and checkout (Day 20-21)
- Instrument high voltage activation (Day 15 - 32)
- Dynamic balancing (Day 32 - 37)
- Attitude inversion (approximately Day 76, and every 6 months thereafter)





#### Orbital Characteristics

Apogee .....	9.0 Earth radii
Perigee .....	1.8 Earth radii
Inclination .....	86°
Orbit period .....	17.38 hours
Eclipse period (maximum) .....	90 minutes
Sun angle (varying) .....	90° to 154°
Spin rate .....	10 rpm

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# LAUNCH VEHICLE

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A Delta Model 7925-10 (long-tank, three-stage, nine solids) launch vehicle designed, built, and launched by the McDonnell Douglas Aerospace Company (MDAC) under the technical direction of NASA/GSFC, will be used to launch the POLAR laboratory from Vandenberg Air Force Base, CA. The Delta is a reliable, low-cost vehicle that has been 99-percent successful over the past 25 years.

The three-stage launch vehicle has an overall length of 125.2 feet (38.2 meters) and a maximum body diameter of 8 feet (2.4 meters).

## FIRST STAGE

The Delta first stage is powered by an RS-27 Rocketdyne engine using liquid hydrocarbon propellants and nine strapped-on Hercules graphite-epoxy motors to augment the first-stage performance. Six motors are ignited at liftoff and the remaining three are ignited in flight.

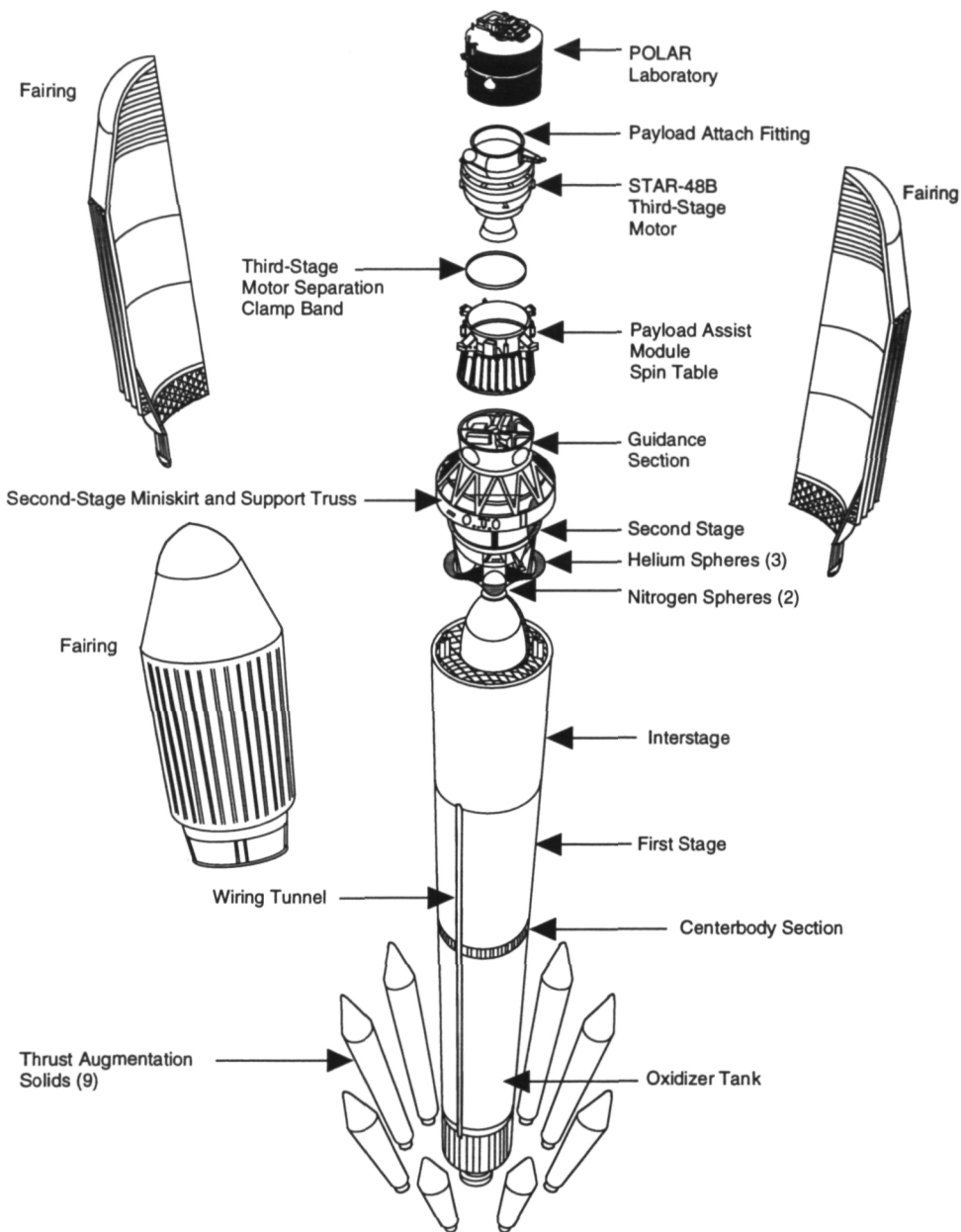
## SECOND STAGE

The Delta second stage is powered by an Aerojet AJ10-118K engine using liquid propellants. During powered flight, the second-stage hydraulic system gimbals the engine for pitch and yaw control. A redundant attitude control system (RACS) using nitrogen gas provides roll control. The RACS also provides pitch, yaw, and roll control during unpowered flight. The guidance, control, and navigation system (GC&NS), located in the forward section of the second stage, is operated by a guidance computer to steer the launch vehicle during flight.

## THIRD STAGE

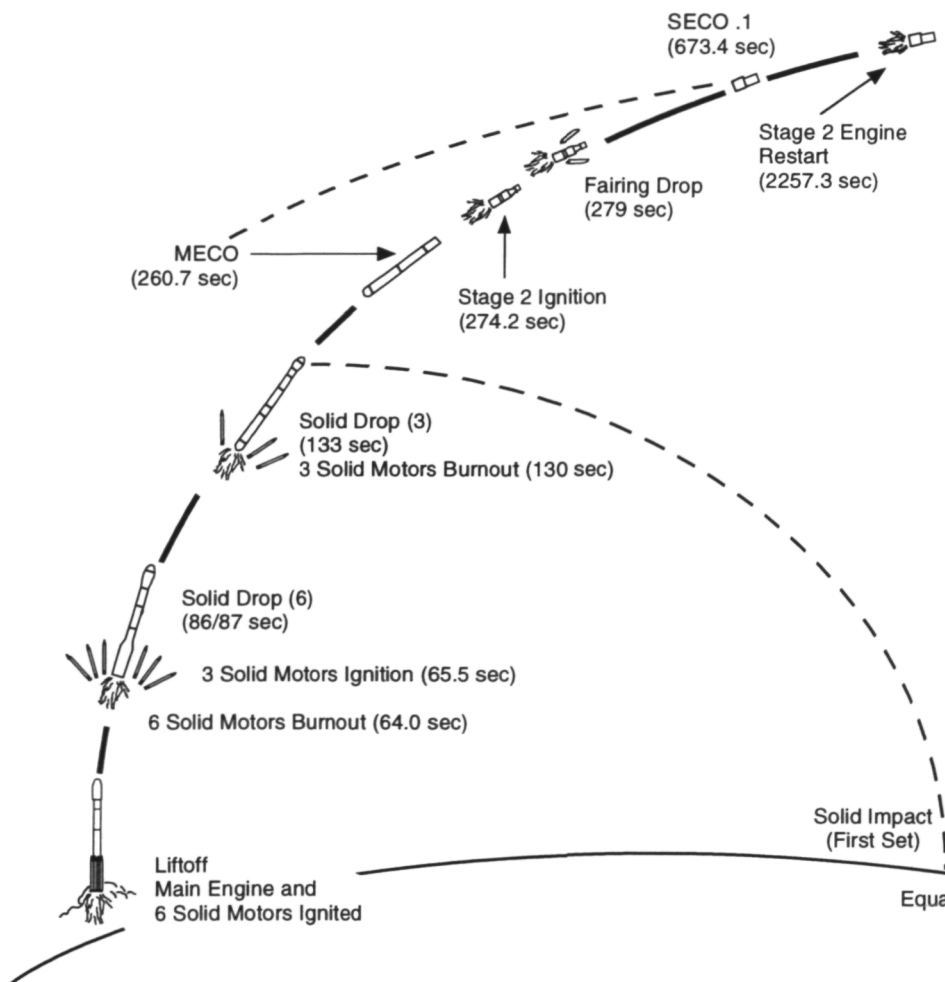
The Delta third stage consists of a Thiokol STAR-48B solid rocket motor (SRM), a payload attach fitting with a nutation control system (NCS), and a spin table containing small rocket motors for spin-up of the third stage and laboratory. The payload attach fitting (PAF), secured to the third stage, fastens the laboratory to the launch vehicle. The NCS, using monopropellant hydrazine, maintains orientation of the spin-axis of the SRM/laboratory during third-stage flight until just before laboratory separation. An ordnance sequence system is used to release the third stage after spin-up, to fire the STAR-48B SRM, and to separate the laboratory following motor burnout.

A 10-feet (3-meter) diameter Delta fairing, attached to the forward face of the third stage, protects the POLAR laboratory from aerodynamic heating during the boost flight.



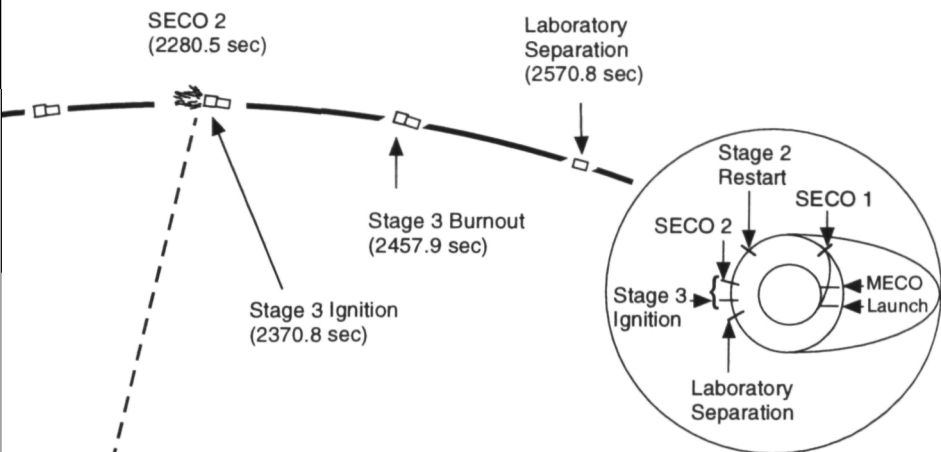
**Launch Vehicle Detailed View**

# LAUNCH AND INJECTION INTO ORBIT



**Delta II 7925-10 Mission Profile - POLAR Mission**





### Three-Stage Mission Profile

#### Event Times

Event	Time From Liftoff (Seconds)
<b>First Stage</b>	
Main engine ignition (liftoff)	0
Stage 1 and solid motors ignition (6 solids)	0
Solid motors burnout (6 solids)	64.0
Solid motors ignition (3 solids)	65.5
Solid motors jettison (3/3 solids)	86/87
Solid motors burnout (3 solids)	130
Solid motors separation (3 solids)	131.5
MECO	260.7
<b>Second Stage</b>	
Stage 2 ignition	274.2
Fairing drop	279
SECO 1	673.4
Stage 2 engine restart	2257.3
SECO 2	2280.5
<b>Third Stage</b>	
Stage 3 ignition	2370.8
Stage 3 burnout	2457.9
<b>Laboratory</b>	
Laboratory separation	2570.8

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# GGS MISSION OPERATIONS

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Mission operations will be conducted from GSFC for the POLAR laboratory using NASA institutional and GGS-unique support facilities. These facilities provide:

- Command and control
- Command management
- Orbit and attitude computation
- Mission analysis
- Data capture and processing
- Science operations

## JPL/DSN SUPPORT

The DSN is located at three Deep Space Communications Complexes (DSCCs). The DSCC sites are located at Goldstone, California, Canberra, Australia, and Madrid, Spain. The overall control of these stations is provided by the JPL in Pasadena, California. The JPL/DSN provides mission support for:

- Command
- Tracking
- Data acquisition

## FLIGHT OPERATIONS TEAM

The GSFC Flight Operations Team (FOT) is responsible for conducting and coordinating the following POLAR mission operations procedures:

- Control of POLAR laboratory and instruments
- Health and safety
- Evaluation of laboratory performance
- Command management
- Maintenance of POLAR-related data bases
- Coordinating JPL/DSN scheduling (including resolution of scheduling conflicts)
- Data acquisition management
- Science and laboratory operations coordination
- Implementing scientific instrument operations plan

## SCIENCE PLANNING AND OPERATIONS FACILITY SUPPORT

The Science Planning and Operations Facility (SPOF) for POLAR scientific instruments will support the FOT for planning science operations. The SPOF and FOT are responsible for preparing instrument operations schedules and command sequences, which are forwarded to the Command Management System (CMS) at GSFC for implementation.

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## INTER-ELEMENT COMMUNICATIONS

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Several NASA and GSFC facilities will provide electronic and voice communications between ground system elements during the GGS Mission:

**NASCOM** – The NASA Communications (NASCOM) system is a global communications system consisting of diversely-routed voice, high-speed data, and wideband data communications channels used for operational data and voice communications.

**PSCN** – The Project Support Communications Network (PSCN) is NASA's non-operational (administrative) communications network.

**LACN** – The Local Area Computer Network (LACN) is a mixed-media computer network used for GSFC-wide computer-to-computer communications.

**NSI** – The NASA Science Internet (NSI) is a NASA-sponsored, worldwide network, which has network connections throughout the United States, Japan, and Europe. This network also interconnects to the Digital Equipment Corporation (DEC) Network (protocol) - based Space Physics Analysis Network (SPAN). So information can be quickly and easily shared, all investigators are interconnected via the NSI.

**MODLAN** – The NASA Mission Operations and Data Systems Directorate (MO&DSD) Local Area Network (MODLAN) is the network used by MO&DSD elements for operational, computer-to-computer data communications.

**CCTV** – The Closed Circuit Television (CCTV) is used for transmission of operational data displays between mission support elements at GSFC, such as Generic Data Capture Facility (GDCF)-to-POCC data quality displays and POCC-to-Flight Dynamics Facility (FDF) real-time telemetry displays.

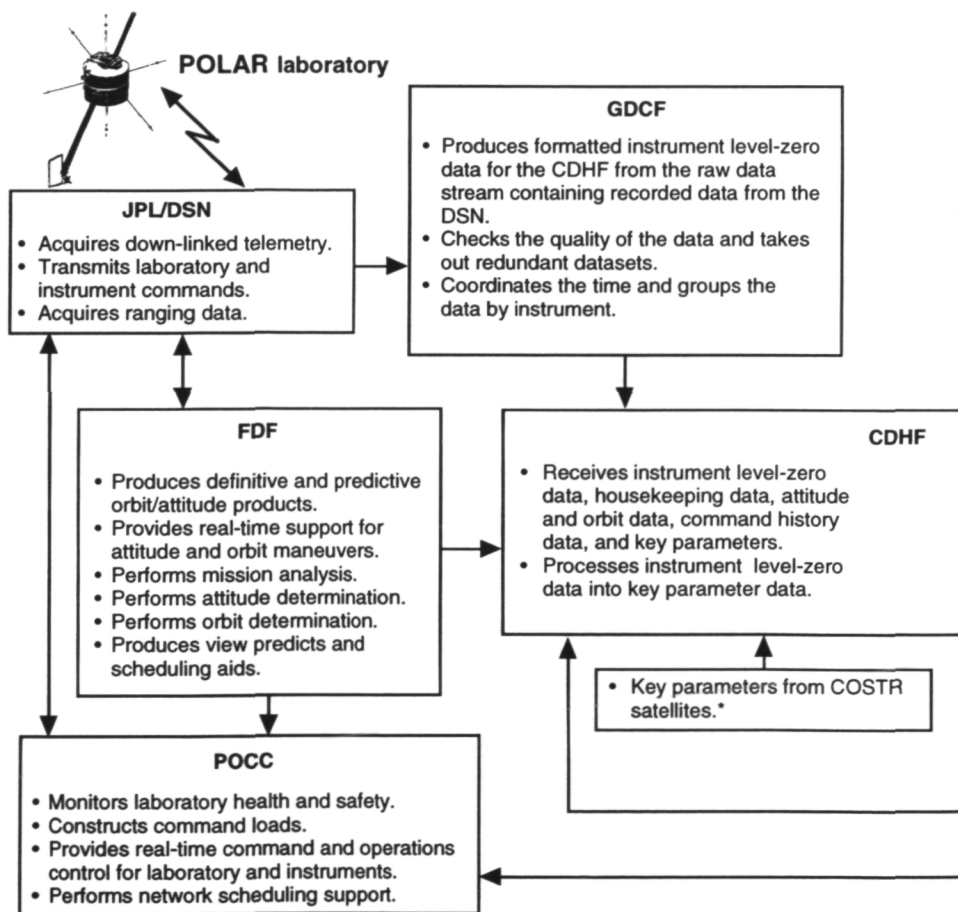
**TLAN** – The Transportable Payloads Operations Control Center (TPOCC) Local Area Network (TLAN) is NASA's Ethernet-based Local Area Network (LAN) used for communications between TPOCC elements.

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# GROUND SYSTEM

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An important element of the GGS Program is the special provisions for handling data collected by the WIND and POLAR laboratories. To successfully attack the scientific problems that bear on the solar dynamics and global behavior of geospace, scientific investigators located throughout the world must be able to compare and combine measurements provided by multiple scientific instruments on board GGS, COSTR, and other ISTP Science Initiative-related missions. The ground segment of the GGS Program uses both existing NASA institutional support facilities and GGS-unique support facilities to accomplish the overall data acquisition and analyses. The major elements of the ground system and their functions are shown below.



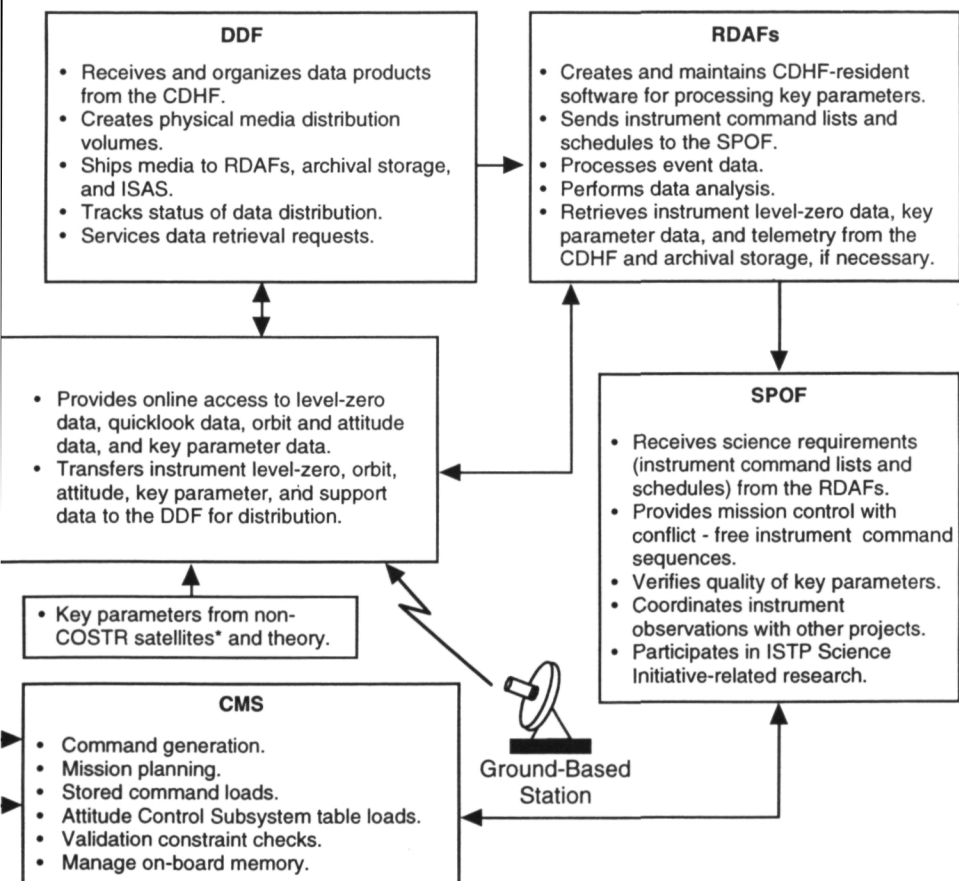
\*COSTR Satellites: Geotail, SOHO, and CLUSTER

## LEGEND:

- CDHF – Central Data Handling Facility (2)
- RDAF – Remote Data Analysis Facilities (2)
- SPOF – Science Planning and Operations Facility (2)
- GDCF – Generic Data Capture Facility (1)
- DDF – Data Distribution Facility (1)
- JPL/DSN – Jet Propulsion Laboratory/Deep Space Network (1)
- FDF – Flight Dynamics Facility (1)
- POCC – Project Operations Control Center (1)
- CMS – Command Management System (1)

(1) NASA Institutional support facilities

(2) GGS-unique support facilities



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## POLAR KEY PERSONNEL

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### NASA/GSFC

- Project Manager
- GGS Project Scientist
- POLAR Project Scientist

Mr. Joseph A. Dezio  
Dr. Mario H. Acuña  
Dr. Robert A. Hoffman

### NASA HEADQUARTERS

- Program Manager
- Program Scientist

Mr. William T. Huddleston  
Dr. Robert L. Carovillano

### LOCKHEED MARTIN

- Program Manager

Mr. Raymond A. Lauer

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## GLOSSARY

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ACAD	Attitude Control and Determination
BOL	Beginning of Life
C&DH	Command and Data Handling
CAMMICE	Charge and Mass Magnetospheric Ion Composition Experiment
CANOPUS	Canadian Auroral Network for Origin of Plasmas in Earth's Neighborhood Program Unified Study
CAP	Command Attitude Processor
CCTV	Closed Circuit Television
CDHF	Central Data Handling Facility
CDU	Command Distribution Unit
CEPPAD	Comprehensive Energetic-Particle Pitch-Angle Distribution
CLUSTER	Plasma Turbulence Laboratory
CMS	Command Management System
COSTR	Collaborative Solar-Terrestrial Research
DARN	Dual Auroral Radar Network
DDF	Data Distribution Facility
DE	Dynamics Explorer
DEC	Digital Equipment Corporation
DOE	Department of Energy
DPM	Despun Platform Mechanism
DSCC	Deep Space Communications Complexes
DSN	Deep Space Network
EFI	Electric Fields Instrument
EOL	End of Life
ESA	European Space Agency
FDF	Flight Dynamics Facility
FOT	Flight Operations Team
GC&NS	Guidance, Control, and Navigation System
GDCF	Generic Data Capture Facility
GGS	Global Geospace Science

GOES	Geosynchronous Operational Environmental Satellite
GSFC	Goddard Space Flight Center
hemi	hemispheric
Hydra	Fast Plasma Analyzer
IMF	Interplanetary Magnetic Field
IMP	International Magnetosphere Physics
ISAS	Institute of Space and Astronautical Science
ISTP	International Solar-Terrestrial Physics
JPL	Jet Propulsion Laboratory
LACN	Local Area Computer Network
LAN	Local Area Network
LANL	Los Alamos National Laboratory
MAMI	Modeling of the Atmosphere-Magnetosphere-Ionosphere
MDAC	McDonnell Douglas Aerospace Company
MECO	Main Engine Cutoff
MFE	Magnetic Fields Experiment
MHD	Magnetohydrodynamics
MHz	Megahertz
MO&DSD	Mission Operations and Data Systems Directorate
MODLAN	MO&DSD Local Area Network
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications
NCS	Nutation Control System
NOAA	National Oceanic and Atmospheric Administration
NRZ	Non-Return-to-Zero
NSI	NASA Science Internet
PAF	Payload Attach Fitting
PIXIE	Polar Ionospheric X-Ray Imaging Experiment
PM	Phase Modulation
POCC	Project Operations Control Center
PRM	Perigee Raise Manuever
POLAR	Polar Plasma Laboratory
PSCN	Project Support Communications Network



PSE	Power Subsystem Electronics
PSI	Plasma Source Instrument
PWI	Plasma Waves Investigation
RACS	Redundant Attitude Control System
RCS	Reaction Control Subsystem
RDAF	Remote Data Analysis Facilities
R <sub>c</sub>	Radii
rpm	revolution per minute
SCAMA	Switched Conferencing and Monitoring Arrangement
SECO	Second Stage Engine Cutoff
SEPS	Source-Loss Core Energetic Particle Spectrometer
SESAME	Satellite Experiments Simultaneous with Antarctic Measurements
SOHO	Solar and Heliospheric Observatory
SPAN	Space Physics Analysis Network
SPOF	Science Planning and Operations Facility
SRM	Solid Rocket Motor
TCS	Thermal Control Subsystem
TIDE	Thermal Ion Dynamics Experiment
TIMAS	Toroidal Imaging Mass-Angle Spectrograph
TLAN	TPOCC Local Area Network
TPOCC	Transportable Payloads Operations Control Center
UVI	Ultraviolet Imager
VAFB	Vandenberg Air Force Base
VIS	Visible Imaging System
WIND	Interplanetary Physics Laboratory

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## NOTES

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